A Critical Chain Perspective to Support Management Activities in Dynamic Production Networks

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Abstract— **Collaborative networks are typically assumed to bring clear benefits and competitive advantage to the participating members. However, as the networks are typically formed by heterogeneous and autonomous enterprises, the development of methodologies that facilitates the management process is an important element for the wide adoption of this paradigm. Departing from a brief presentation of the Critical Chain Project Management approach, the paper introduces this approach to collaborative networks and discusses its potential application in the context of a dynamic production networks. Finally, experimental results based on data from a network in construction industry are presented.**

Index Terms— **Collaborative networks, Production management, Production systems, Project management.**

I. Introduction

THE business environment has changed radically during last years and news changes will certainly continue [1].

Nowadays, trends are a feature of the business world. Some are imagined others are based on fashion but many are real. Considered unusual and indeed suspicious until a few years ago, cooperation between enterprises has gained a new dimension in the last decade.

In today's society, collaborative environments manifest in a large variety of forms, such as virtual organizations (VO), virtual enterprises (VE), dynamic supply chains, professional associations, industry clusters, virtual communities (e.g. Linux developers), collaborative virtual laboratories, virtual breeding environment (VBE), etc., where most of these collaborative environments imply some kind of *organizational configuration* of activities within the environment and its constituents. These manifestations are called collaborative networked organizations (CNOs) which represents a different form of inter-organizational co-working different from traditional forms of collaborative environments that have been taking place in virtual communities, namely the none business oriented ones- e.g. Wikipedia contributors in which people may volunteer and come together to improve the general knowledge, but there is no prior plan how their activities should go [2].

On the other hand, in most literature on production management there is an assumption that production networks can bring clear intuitive advantages to its members and represent even a survival factor in turbulent socio-economic scenarios. On the basis of these expectations are, among others, the following factors: sharing of risks and resources, joining of complementary skills and capacities, acquisition of an apparent higher dimension, access to new / wider markets and new knowledge.

According to Penã and Arroyabe [3] there are three environmental factors that have had the most decisive influence to encourage cooperation among organizations. The first is economic globalization. The world economy at the start of the twenty-first century is experiencing one of its moments of greatest dynamism and change. This dynamism is reflected in the growing interdependence of markets for goods, services and factors of production. The second factor is the increase in business uncertainty. The speed under which changes are occurring in the economic world is introducing large uncertainty. This is specially the case in business areas where constant transformations, resulting from reductions in technological and product life-cycles, improvement in productive processes, and so on, which are often difficult to predict, demanding greater follow-up capacity from enterprises in order to adapt to the new surrounding conditions.

Finally, the third feature is the high level of competitive rivalry. The increased customer requirements and market saturation are forcing the enterprises to constantly dig deeper in their search for competitive advantages to improve their position in the market. As a result of this, there is a tendency for enterprises to concentrate on core know-how, or on those aspects of the added value chain they really master.

However, in spite of these advantages, it is also frequently mentioned cooperation also involves additional overheads (e.g. transaction costs) and several risks and the lack of tools tailed to support management activities is an obstacle for a wider acceptance of this paradigm [2].

In order to contribute for development of a tool that supports the management activities in a collaborative context the approach suggested by some researches [2] is not to "re-invent the wheel" but rather to take into account and adapt possible contributions from other disciplines. It is, however, necessary to take into account that both these approaches and corresponding tools have been developed for different contexts. Therefore their application to dynamic network paradigm requires assessment, adaptations, and further developments. Furthermore, there are a large number of

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different perspectives in a dynamic production network, which cannot be covered by a single theory or single modeling approach.

This paper introduces some discussion about the critical chain in collaborative networks and discusses its potential application in the context of dynamic production networks.

II. Modeling dynamic production networks

In order to support the management activities in dynamic networks context is necessary to develop tools that cover multiple perspectives for different purposes. Identifying and characterizing the tools need to *management purposes* is thus a necessary first step.

As an illustration, let us consider three management perspectives: i) management of relationships ii) management of roles, and iii) management of process. Fig. 1 shows how these management perspectives partition the dynamic network management problem in more tractable sub-problems.

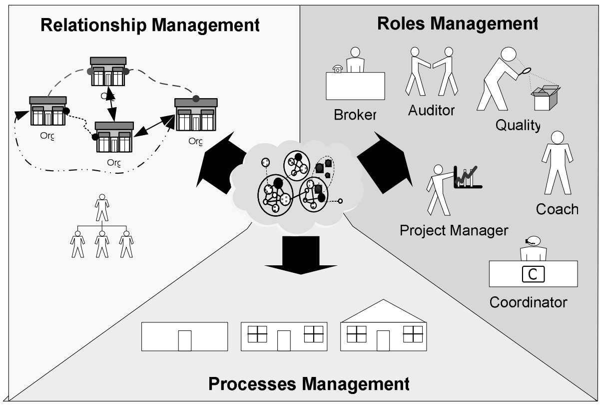

Fig. 1. Three management purposes in dynamic networked organizations

Each of the individual perspectives can be described and supported by specialized methods without having to incorporate the corresponding relationships to the other perspectives, as follows:

- **Relationships Management** – it supports the management of interrelationship forms that can occur between components within a network. For instance, the following types of relationships can be identified:
  - Control relationships – management the authority structure within a network. Such as contractual and cooperation agreements.
  - Dependence relationships – management the dependences between actors and tasks. Such as resources and knowledge dependences.
  - Ownership relationships – management the boundaries of each actor.
  - Social relationships – management the relation among actors within a network. Such as: trust, prestige, benefits distribution and Intellectual Property Right.
- **Roles Management –** Departing from description of all roles and their positioning within the network structure. The roles management implicitly defines a topology of interactions and can describe a network structure in terms of "master role" and "slave role".
- **Processes Management -** It focuses on dynamic courses of events. Some generic concepts such as activity and actor, time dependencies such as equal, during, starts, finishes, and resource-related perspectives such as necessary, sufficient, have to be supported by this tool.

III. Approaches to Support Management Activities

Table 1 shows some promising theories and approaches that can contribute for development of tools that support management activities in dynamic networks [4]. However, the table is not exhaustive and others existing and/or emerging theories and approaches might also have a positive contribution to support management activities.

In order to model network uncertainty or to manage how and why networks activities are performed from a process management perspective the Critical Chain Project Management (CCPM) approach can be a useful instrument to the network coordinator, and also to network members.

IV. The CCPM Approach

The Critical Chain Project Management (CCPM) approach was introduced by Goldratt in 1997 as an alternative approach to classical approaches in Project Management [5] as PERT (Program Evaluation and Review Technique) or CPM (Critical Path Method). CCPM is one applied component of the Theory of Constraints (TOC) which can be seen as a prescriptive theory promoting systems performance improvement by the identification and improvement of the main constraint of any system in a systematic, successive and continuous way [6].

CCPM integrates one technical component of planning, schedule and time management of project networks and operational components which include specific human action and behaviors like the r*oadrunner mentality* which promote the use of dedicated resource, fast activity execution and report expected activity conclusion and its conclusion as soon as concluded. According to CCPM approach the network planning and schedule process is developed in four fundamental phases:

A. *Network Building*

The network is built in two phases: firstly the network is created using an inverse logic i.e. from the last to the first activity. During this phase the project management team should identify the deliverable associated at which activity, the prerequisites and assumptions assumed. During the second phase the classical direct logic is used to verify and reformulate if necessary the activities relations identified in the first phase. The output of this approach will be an activity on node (AON) network with preferably F*inish-to-Start* activities and assumed resource constraints.

B. *Activity Durations Estimation*

The activity duration is probabilistic [5] and at least two estimations have to me made: one target duration (generally median or average duration) and one pessimistic duration.

C. *Critical Chain Identification*

The Critical Chain (CC) is the set of activities scheduled according to a *As Late as Possible* (ALAP) process that defines the project duration, based on activity durations, technical and resource dependencies.

D. *Time Buffers Insertion and Network Scheduling*

The time buffers are time blocks incorporated on schedule in special points of the network to reduce the impact of duration variability of the activities on network.

Fig. 2 illustrates a very simplified AON network with six activities (from A1 to A6) where the bar size defines the activity duration.

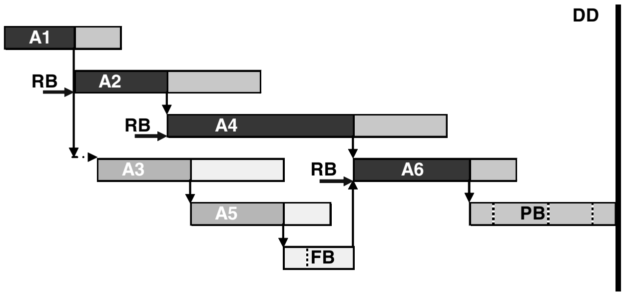

Fig. 2. CCPM Scheduling

In Fig. 2 the Critical Chain (CC) is given by path A1, A2, A4, A6. To protect the project Due Date (DD) against CC duration variability a time buffer designed by Project Buffer (PB) is introduced after the last activity of the project. The PB is set to work as a time pillow or damper against schedule variability of critical chain activities as well as a visual register of the time impact of the randomness occurred in the network activities. This register is used as the control tool of the project execution and is intended to be efficient, focused and global.

To protect the CC from the variability of non critical activities durations (A3 e A5) another time buffer is inserted in arcs that connects non critical activities and critical activities. This type of buffer is designated by Feeding Buffers (FB).

V. POTENTIAL APPLICATION IN DYNAMIC PRODUCTION NETWORK CONTEXT

The concept of dynamic network is considered by a growing number of authors [1] as a temporary network of enterprises, that is formed to explore a business opportunity; a Project is also viewed as "a temporary endeavor undertaken to create a unique product, service or result" [7] that can be modeled by an activity network.

Assuming the structure of a dynamic network can be managed through a project network where the activities are replaced by enterprises and the links between activities represent dependences among them, both concepts can be related as illustrated in Fig. 3.

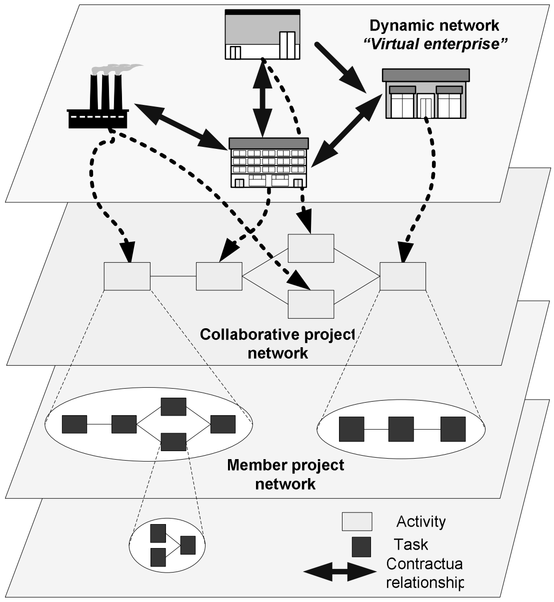

Fig. 3.. Relation between project network and dynamic network

VI. EXPERIMENTAL RESULTS

The approach described was applied in a major civil construction project, which comprised the construction of two similar towers at the municipality of Lisbon. According to the contract agreement the main goal was build the towers within the time settled. The contractor was in charge for the planning, scheduling and construction, worked with several subcontractors, resulting in a collaborative network with different entities and activities to develop [8].

In terms of management tools, the first tower was managed applying classical tools for project management while the second one was managed based on a CCPM collaborative approach.

Based on this approach the process of planning and scheduling the resources was applied at macro level where each member of the collaborative network had a set of tasks and sequences which were not programmed in the baseline of the collaborative project network but at the company project level.

After identified the critical chain of the collaborative project network the time buffers were introduced. The size of all time buffers was calculated according to SMC method [9]. This method consists in sizing feeding buffers, in an ALAP scheduling, applying Monte Carlo Simulation for each activity. With SMC the size of the buffers were reduced and buffer consumption improved without exceed the due date of the project [10].

During the execution of the project the scheduling update process was done considering not just the percentage complete of the undergoing activities but also using estimated and approved activity remaining durations. If needed to reduce project buffer consumption target duration were also changed in activities immediately following the undergoing activities. For that each member of the collaborative project network have to evaluate and if required, reschedule his member project network according with the changes approved for the collaborative network, in site reunions.

If we compare the activities baseline durations of the collaborative network and the real durations, one can see that the majority of the durations were not respected (Fig. 3).

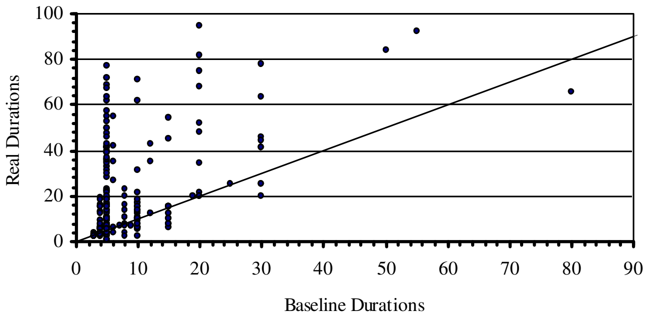

Fig. 3. Real durations *versus* Baseline durations

However, comparing the scheduled durations of the collaborative project network with the real ones, it can be seen that there is a greater linearity relation (Fig. 4). These results shows a more aligned schedules durations with the real activities durations, as a result of the CCPM management process used.

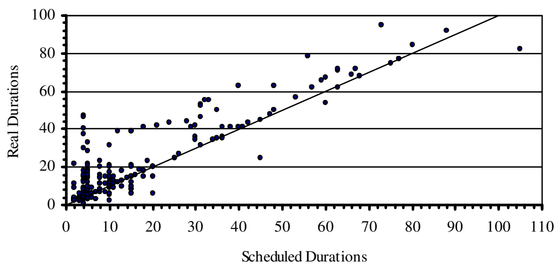

Fig. 4. Real durations *versus* Schedule durations

As illustrated in Fig. 5 and in opposition to the First tower, managed according to traditional approaches, the application of the CCPM approach allowed to anticipate the schedule conclusion of the CCPM tower, managed using the proposed approach.

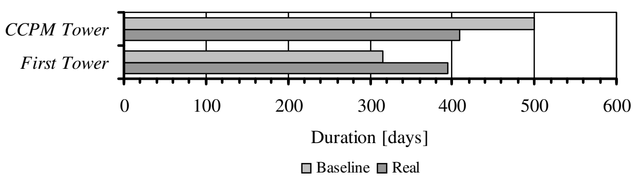

Fig. 5. Finishing phase durations of First Tower and CCPM Tower

VII. Conclusion

Forms of cooperation have changed over the years and have become increasingly visible and complex. However, the processes management in which the cooperation is initiated and developed seems to be shrouded in some mystery. One of the main weaknesses in the area is the lack of appropriate theories, consistent paradigms and formal modelling tools to offer a systematic overview of the main topics which contribute to understand different analytic viewpoints and to draw some comparisons between them.

Developing models and tools that support management activities in collaborative environments will not only help to better understand the area, but also for a wide adoption of the collaborative networks paradigm in its various manifestation forms.

Some preliminary steps in this direction, inspired in critical chain concepts were presented. Initial results illustrate the applicability of the suggested approach. Further steps are necessary towards the elaboration of a robust tool as well its validation.

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Table 1: Promising disciplines vs. management purposes

THEORIES / MODELS	*Short Description*	Applicability to support dynamic network management	Covered management purpose
Game Theory	A mathematical framework designed for analyzing the interaction between several agents whose decisions affect each other. An interactive situation is described as a *game* that has an abstract description of the players (agents), the courses of actions available to them, and their preferences over the possible outcomes. It is assumed that players employ rational decision-making, that is, each player's objective is to maximize the expected value of his own payoff, which is measured in some utility scale.	• Non cooperative game theory: good for selecting partners, sustaining cooperation and trust • Cooperative game theory: distribution of responsibility and resources.	• RELATIONSHIPS MANAGEMENT • ROLES MANAGEMENT
Complex theory	Complexity theory deals with systems that show complex structures in time or space, often hiding simple deterministic rules. A complex system can be understood as any network of interacting agents (processes or elements) that exhibits a dynamic aggregate behavior as a result of the individual activities of its agents. Some important characteristics of complex systems include: non-determinism, limited functional decomposability, distributed nature of information, and emergence and self-organization. Emergence is in fact one of the most important properties of complex systems, what makes this paradigm an appealing approach for the analysis of advanced collaborative networks.	• Analysis of self-organizing behavior, • Learn how to manage chaotic dynamics.	• PROCESS MANAGEMENT
Social Actors Networks theory	Based on graph-theoretic concepts and basic statistics analysis it is used to model and explain social structures. In other words it is focused on uncovering the patterning of actors' interaction. It involves the mapping and measuring of relationships and flows between actors. The nodes in the network are the actors while the links show relationships or flows between the nodes.	• Analysis of social and organizational structure of networks (connectiveness, trust, awareness, etc.) • Creation / reconfiguration phases of collaborative networked organizations.	• RELATIONSHIPS MANAGEMENT • ROLES MANAGEMENT
Multi-Agent Systems	A multi-agent system is a loosely coupled network of problem-solver entities that work together to find answers to problems that are beyond the individual capabilities or knowledge of each entity. Hence, it is concerned with coordinating intelligent behavior among a collection of autonomous intelligent agents, how they can jointly coordinate their knowledge, goals, skills and plans to take action or to solve problems.	• Coalition formation and negotiation • Simulate self-organizing behavior	• PROCESS MANAGEMENT
SCOR – Supply Chain Operations Reference model	It is a process reference model for supply-chain management which describes the business activities associated with all phases of satisfying a customer's demand. SCOR uses graphical decomposition of processes from the Level 1 Functions PLAN-SOURCE-MAKE-DELIVER-RETURN to level 3 process elements. Modelling of inter-enterprise processes is done through connecting one process element (i.e. source) from one SC member to the process element (i.e. deliver) of another SC member.	• For management SCOR offers a set of Key Performance Indicators (KPI's) that can be used to measure and compare (benchmarking) the performance of companies in their domains.	• PROCESS MANAGEMENT
Metaphor Theory	Metaphors are an integral part of our society and language (informal or semi-formal language that can use graphic description like bubbles, arrows, charts, matrices) which makes it a form of communicating that is deeply ingrained and understood intuitively by Western cultures. That is one of the most important tools for trying to comprehend partially what cannot be comprehended totally.	• Quick description for human communication (a possible help in expressing complex ill-defined concepts) • Use in early stages (conceptual design)	• RELATIONSHIPS MANAGEMENT • PROCESS MANAGEMENT • ROLES MANAGEMENT